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Management of Corrosion in Aging Military Systems

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Abstract

This paper discusses research in Australia into the impact of corrosion on structural integrity, and reviews the steps being taken to improve the capability of the Australian Defence Force to manage corrosion in aircraft. The aim of the research discussed is to develop useful methodologies which are similar to those already in place for fatigue management and which can therefore be introduced relatively easily, and the paper discusses some of the implications of pursuing this goal of absorbing corrosion into our structural integrity management approaches. The research has already achieved some useful developments in assessing the impact of some types of corrosion, and the paper will discuss these highlights briefly to illustrate the methodology being used.

1. DSTO approach to corrosion management.

1.1 Background

Increasing economic pressure has encouraged extension of the service lives of many military aircraft fleets well beyond their original design goals. Since the incidence of corrosion tends to increase with aircraft age, its importance as a life limiting form of degradation has increased in these fleets.

The Defence Science and Technology Organisation (DSTO) has provided scientific and technical support to Australian Defence Force (ADF) aviation for many decades, and as part of this periodically undertakes reviews of the engineering problems affecting military aviation in Australia. The author and a colleague Dr Bruce Hinton visited all ADF aviation bases in the early 1990's as part of this program [1], and observed a common thread to the discussions with base personnel - their concern about the rising cost of corrosion repairs, and the increasing impact of corrosion-related maintenance on aircraft availability. Obviously, this would become a more severe burden with aging of the ADF fleet, directing attention to the need for a strategy for management of corrosion. Examples of the cost burden of corrosion, for detection, repair and repainting of some aircraft types in the ADF fleet, are shown in Figure 1; these are broadly comparable with the experience of other military operators.

Obviously, the introduction of more effective corrosion preventive measures would be a cornerstone of any strategy; key measures identified were:

(a) improved training in corrosion recognition and treatment.,
(b) wider use of corrosion preventive compounds (CPCs) during regular maintenance, and
(c) washing of aircraft with water containing inhibitors.

DSTO initiated research to develop each of these areas [2], examining the effectiveness of CPCs, for example, and preparing a handbook for ADF personnel on corrosion recognition [3]. Introducing these approaches to service is still a key target for DSTO and the ADF. The corrosion control aspects of the approach – a program led by Dr Bruce Hinton – have been particularly successful in reducing the progression of corrosion using Corrosion Preventive Compounds

Paper presented at the RTO AVT Specialists' Meeting on "Life Management Techniques for Ageing Air Vehicles", held in Manchester, United Kingdom, 8-11 October 2001, and published in RTO-MP-079(II).

(CPC's);. Since 1993, there have been many cases of corrosion which have been arrested by the one-time or repeated application of CPC's; examples include tailplane corrosion and centre section corrosion in the Macchi MB326H, and the stress corrosion cracking (SCC) in BL20 longerons and main landing gear vertical beams in C130. The latter case has been managed for approximately six years by inspection and CPC application, with no evidence of significant additional SCC growth. Concern still remains, however, about our ability to adequately assess the impact of the corrosion which, while inactivated, remains in the component and will impact the structural integrity management of the aircraft.

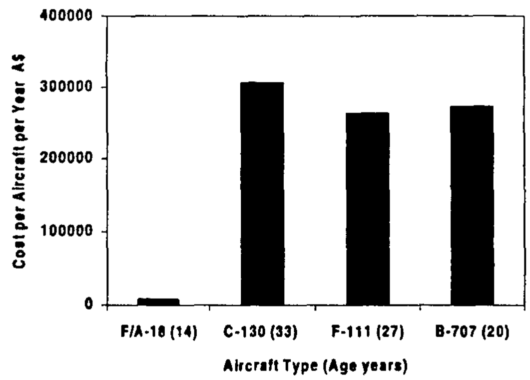

Figure 1. Cost of corrosion for examples of aircraft types from the ADF fleet.

1.2 Corrosion impact.

The ADF has experienced several cases where the presence of corrosion raised uncertainties over the continued airworthiness of some RAAF aircraft. These cases were resolved, but they showed how structural integrity concerns associated with the detection of corrosion can lead to reduced aircraft availability and substantial increases in maintenance and support costs. Examples which were particularly significant in terms of reduced availability of aircraft included the replacement of spar caps following discovery of stress corrosion cracking in P-3C wing rear spar caps, and in Macchi MB326H tailplane spar caps [4]. In both cases, it had been observed that the replacement of components was necessary because no suitable methods existed for analysing the impact of the corrosion damage on static strength and fatigue performance. A further example – stress corrosion in BL20 longerons in C130 aircraft – led to attempts to assess the corrosion by representing it as cracking, but with limited success because of uncertainty about the exact configuration of the damage and about the local stressing.

1.3 Decision-making tools for corrosion impact assessment

DSTO undertook a detailed review [5] of the possible approaches to managing the impact of corrosion on structural integrity. This review observed that the inefficiency in the "fix-when-found" approach to corrosion management arose from a perceived need to remove most corrosion whenever it is detected, a conservative approach required because corrosion lies outside the parameters normally forming the basis of structural integrity management. The problem of assessing corrosion impact was not confined to major fleet-threatening cases; methods for avoiding unwarranted repairs could dramatically reduce maintenance times, simply by allowing continued operation of aircraft with identified corrosion defects until a more convenient maintenance opportunity. The key proposal from the review was that the ADF adopt an "inspect and manage" philosophy, and that research focus on improved methods for corrosion assessment, to allow decisions to be made concerning the effect of corrosion on structural integrity, and hence to determine the need for repair.

The development of decision-making tools for assessing the structural integrity impact of corrosion formed the second part of the DSTO corrosion management strategy.

Only a small proportion of aircraft accidents and incidents are attributed directly to the presence of corrosion, but the potential for corrosion damage and corrosive environments to reduce structural

integrity in aircraft cannot be assumed to be negligible. The review concluded that since the ADF already had structural integrity management plans in place for each platform, it was appropriate to incorporate corrosion into these structural integrity management approaches. It identified a research program which has been pursued by DSTO, and is developing tools to assist RAAF assess corrosion in a manner compatible with the current management processes for cracking.

1.4 Conditions addressed.

Aircraft design and structural integrity management approaches in current use are customarily validated using benign environments; the effects of either (a) corrosion as an initiator of fatigue cracking (corrosion/fatigue), or (b) corrosive environments accelerating fatigue crack growth (corrosion fatigue), are not sufficiently understood to permit them to be incorporated with confidence, and on a routine basis, into structural integrity assessments.

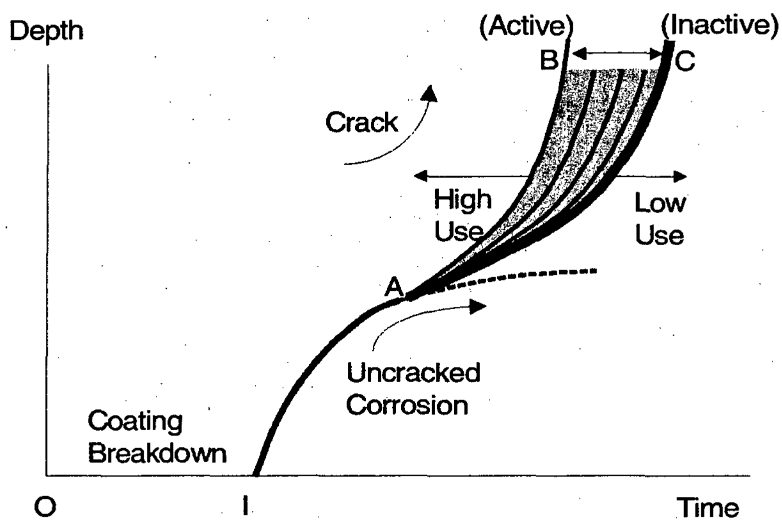

Figure 2. Schematic of the growth of corrosion and fatigue cracking with time, illustrating the significant parts of the life cycle.

A whole-of-life prediction capability for corrosion, and any fatigue cracking which develops from it, is clearly desirable, and research into the various life phases could well lead to valuable corrosion management methods. Unfortunately, reliable ab initio prediction will require resolution of many complex and uncertain factors [6], for example, coating breakdown time OI in Figure 2, and its dependence on coating condition and maintenance intervention is clearly significant, as is the complex interaction between fatigue cracking, environment and materials parameters (ie. the shift from crack growth AC in an inert environment to AB in a corrosive environment). Consequently, effective prediction capability will probably rely on data from fleet experience. The ADF fleet is relatively small in world terms, and in itself is unlikely to provide sufficient data to allow reliable prediction, although data from Australian experience could add significantly to other data. A key factor is the development of data management strategies.

Two approaches identified were (i) improved data collection and management to support empirical predictive approaches, and (ii) DSTO research into selected parts of the corrosion life cycle. This research, while generally supporting the longer term goal of a prediction capability, would focus on aspects which would yield useful tools for corrosion management. Accordingly, the DSTO approach was to focus on a limited scenario.

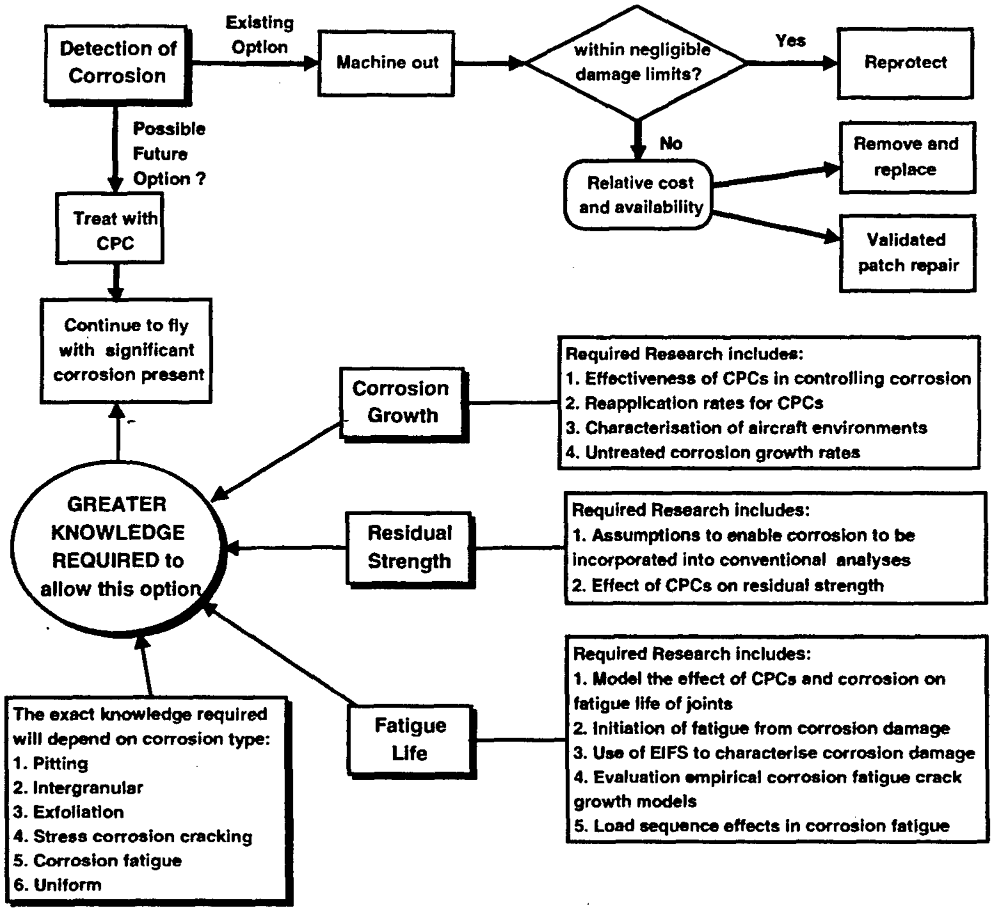

Figure 3. From [5]. Research required to allow continued component service after discovery of corrosion.

The first simplification was to consider the situation where corrosion is discovered in a structurally significant location, and to address potential fixes Figure 3 [5]. A key assumption and second simplification (made initially on the basis of limited experience with Macchi and C130 stress corrosion, but supported by subsequent experience) is that a program of application of suitable corrosion preventives can reduce the problem to an inert condition ie. no active corrosion. Hence the problem becomes one of growth of fatigue from a geometrical feature (line AC in Figure 2). Figure 4 represents the decision-making required to allow continued service of a component in such a situation. DSTO has been addressing this part of the life cycle by developing predictive approaches for the remaining life of parts containing such damage.

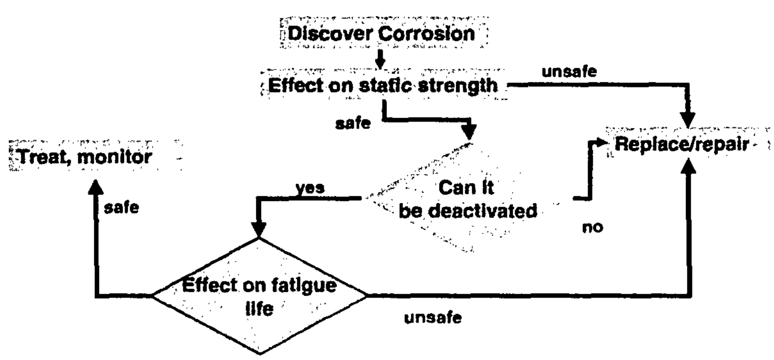

Figure 4. Simple decision tree for continued operation. [5]

2. Progress in tool development

The DSTO research program uses an Equivalent Precrack Size (EPS) approach, correlating features of the corrosion damage to notional fatigue crack sizes, and allowing simple prediction of remaining fatigue life. The different systems on which the DSTO program has focused are:
Fatigue from pitting corrosion, high Kt aluminium alloy
Fatigue from pitting corrosion, low Kt aluminium alloy
Fatigue from pitting corrosion in high-strength steel
Fatigue from exfoliation corrosion
Fatigue from laminar stress-corrosion
Impact of CPCs and environment on joint failure.

Prediction of remaining life for condition (c) ie. pitting in D6ac high strength steel has been particularly successful, with a good match between experimentally-determined lives of pitted specimens and the lives predicted from geometries deduced from measurements on pits. System (a), however, does not produce results which are as consistent; correlation of pit depth and the EPS is better for the steel (Figure 5) since the pits have a more regular morphology. In the aluminium alloys investigated, pit shape shows a higher level of variability.

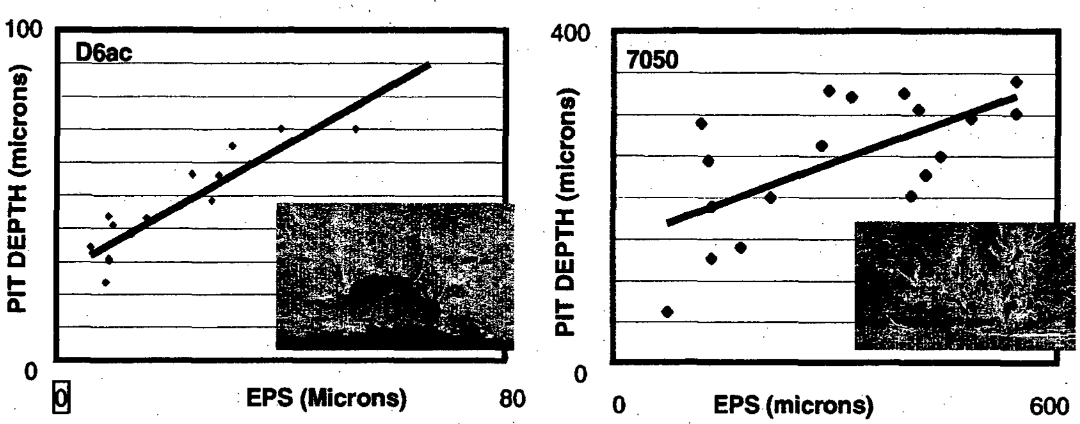

Figure 5. Correlation between pit depth and Equivalent Precrack Size for high-strength steel and 7050 aluminium alloy.

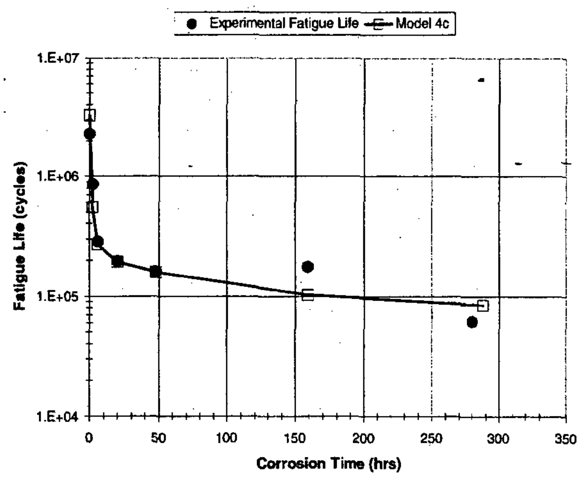

Figure 6. Prediction of remaining life for 2024-T351 aluminium alloy specimens with exfoliation and pitting.

DSTO modelling of crack growth from exfoliation [7] adopts a similar approach to the modelling for pits, by modelling the progression of exfoliation into the body of the material as a pitting-type

process. Observation of the initiation sites for fatigue cracks supported this model, and allowed construction of a notch+crack representation of the process zone at the base of the exfoliation, giving excellent correlation with the experimental fatigue lives of corroded specimens (Figure 6).

3. Transfer to ADF aircraft.

To date, the modelling has assessed simple loading and simple geometries, but shows promise for extension to variable-amplitude loading, and the next stage, a transition to component and assembly testing. The extensive effort expended on protocols for generating corrosion similar to that observed in service is being used to introduce pits into a full-scale wing fatigue article in support of the RAAF F-111 Sole Operator Program.

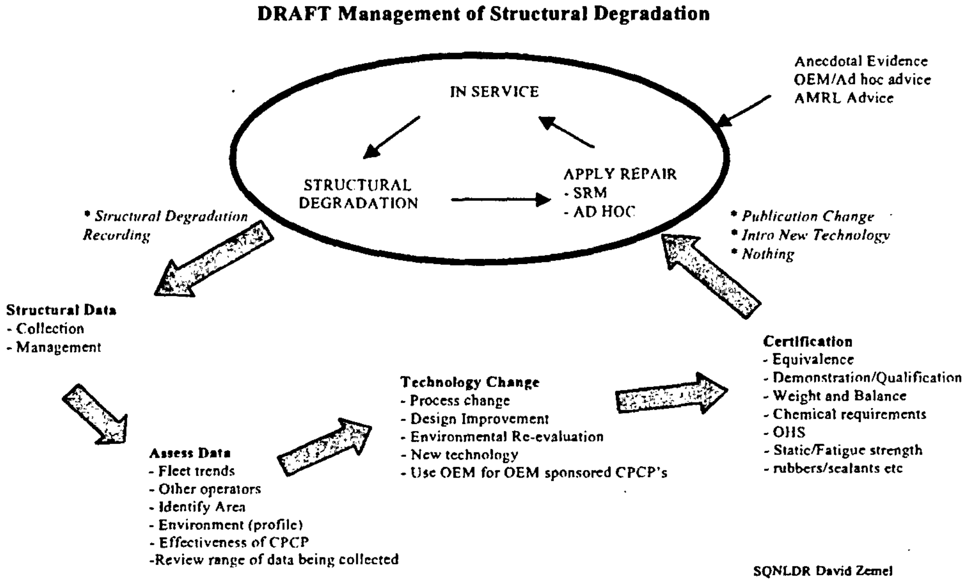

Figure 7. Draft representation of RAAF approach to management of structural degradation [8]. Key elements related to this paper include Structural Degradation Recording, and Technological Inputs from DSTO.

The RAAF manages the airworthiness of ADF aircraft, using Aircraft Structural Integrity Management Plans (ASIMPs) for each system, and is considering a use of the approach shown in Figure 7[8] for managing structural degradation. This approach will address the higher-level aspects of structural damage reporting, and the data storage and processing required to allow tracking of fleet condition, as well as identifying the technological inputs, such as those described in this paper, which are required as inputs to the management approach.

A key element in this approach is the need for structural condition monitoring. The RAAF recognises two main areas for data collection: usage and condition, each of which will provide input to the two key management systems; Fatigue Degradation Management (FDM) and Environmental Degradation Management (EDM). The two management systems will generate input for the fleet processes which control structural integrity and corrosion, and will also allow continuous improvement of the data acquisition and assessment processes being used as part of long term Service Life Assessments (SLA's). The annual work (whether fatigue management or condition monitoring) will be conducted under the ASIP cycle. Figure 8 shows more detail of the data flow through data collection and verification, followed by analysis under the FDM or EDM processes. It is important to note that the same condition and usage data, will be used as input to both management processes; the usage monitoring data will allow improved assessment of corrosion condition, and the identification of structurally significant corrosion will assist in managing structural integrity (by validating, refining or changing SBI and safe-life management programs). The environmental degradation (corrosion, etc.) and changes to the operating

environment (usage) will be assessed under the EDM process, for the purpose of developing progressive changes to corrosion management of the fleet.

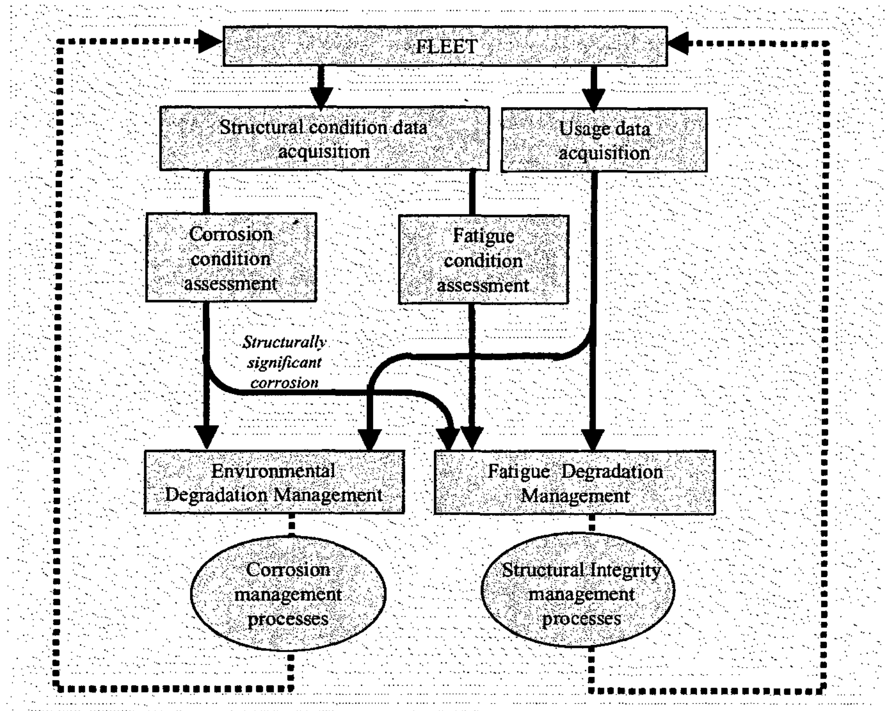

Figure 8. Structural degradation management in RAAF [8].

The RAAF approach is identifying a suite of technological tools for analysis, modification and repair, whose use for fleet operations will be managed under relevant Aircraft Technology Management Programs. The management of corrosion, more specifically, revolves around development of a guide for ASIP managers; much of this will involve adoption of OEM Corrosion Prevention and Control Programs (CPCPs) with modification, where relevant, together with the proactive aspects of corrosion prevention and control discussed earlier in this paper. The decision-making tools discussed in this paper will provide a basis for advice to the system managers who will still need to determine appropriate reactions to corrosion occurrences. It is intended that these tools will be used to address the (hopefully) infrequent occurrences which have high economic/safety impact and which cannot easily be managed by CPCPs or on-condition maintenance programs.

4. Acknowledgments

The author wishes to acknowledge the contributions of several individuals in DSTO and RAAF, to this program of research. Khan Sharp, in particular, was the major contributor to the pitting and exfoliation program referred to in this paper. Bruce Hinton provided information on application and use of CPCs, and SQNLDR David Zemel provided valuable input on the developing RAAF approach to corrosion management.

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